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RESEARCH ARTICLE

Valorization of tropical fruit peel powders: Physico-chemical composition, techno-functional properties, and *in vitro* antioxidant and antidiabetic activities

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ABSTRACT

This study aims to evaluate the physico-chemical composition, techno-functional properties and *in vitro* antioxidant and antidiabetic activities of papaya, pineapple and mango peels for their possible use as functional ingredients. The peel powders were found to possess interesting techno-functional properties, high dietary fiber content (37.77 to 62.26%) and phenolic compounds, namely gallic, ferulic, and p-coumaric acid, catechin, quercetin-3-β-d-glucoside and quercetin. They also showed excellent antioxidant activity, as determined by ABTS (3.63 to 29.8 μM TE/g), DPPH (5.76 to 35.3 μM TE/g), $NO^{\cdot}$ (60.67 to 86.35%) and O_2^{-} (17.56 to 50.64%). Mango peel powders presented the best ability to inhibit the activity of the different enzymes evaluated: modest α-amylase inhibition (51.40%), stronger α-glucosidase inhibitory activities (70.32%), and moderate antiglycation potential (57.15%). Peel powders of these tropical fruits make them suitable to be used as food ingredients with possible health benefits, improving intestinal function and controlling hyperglycemia. Further studies require animal models and, subsequently, in humans.

Keywords: Bioactivities; Nutritional value; Peels; Techno-functional properties; Tropical fruits

INTRODUCTION

Mango, papaya and pineapple are the most popular tropical fruits in the international markets (FAO, 2021) that are consumed fresh or processed as juices, marmalade, jellies, nectars, sauces, wines and desserts. Industrial processing generates byproducts that include unusable pulp, seeds, and peels, together representing up to 52% of the weight of the fruits (Cheok et al., 2018). These byproducts have the potential for reutilization since they contain many valuable substances like dietary fiber and phenolic compounds. Dietary fiber has specific properties, including water and oil holding capacity, improving yield, modifying texture and viscosity in foods (Dhingra et al., 2012). The physicochemical and functional properties of mango peel (García-Magaña et al., 2013; Martínez et al., 2012), pineapple, and papaya byproducts have been investigated (Selani et al., 2016; Nieto-Calvache et al., 2019), comparing their content of dietary fiber and functional properties. Other works have been centered on dietary fiber content and application in food processing of papaya subproducts (Jiang et al., 2021), pineapple pomace (Selani et al., 2014; Montalvo-González et al., 2018), mango peel (Aslam et al., 2014; Pérez-Chabela et al., 2021).

In the case of phenolic compounds, their antioxidant and other properties have been associated with the control of postprandial hyperglycemia (Fabila-Garca et al., 2017); therefore, extracts of byproducts of tropical fruits alone or added to foods could have the potential to mitigate to some extent, several effects of postprandial hyperglycemia. According to The International Diabetes Federation (2021),

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approximately 537 million adults were living with diabetes in 2022. Evidence suggests that diabetic patients are under oxidative stress, which may facilitate the induction and development of complications associated with diabetes.

Inhibition of digestive enzymes α-amylase and α-glucosidase, key enzymes implicated in the intestinal digestion of carbohydrates, is a therapeutic approach to decrease the postprandial rise of blood glucose (Gong et al., 2020), and delaying the early onset of diabetes-associated complications. Regarding diabetic patients, the excess of free glucose produces excessive non-enzymatic glycosylation of proteins; this process eventually leads to the generation of advanced glycation end products (AGEs), which are implicated in the pathogenesis of diabetes (Thakur et al., 2018). Thus, preventing the formation of AGEs is another attractive strategy to prevent the development of diabetic complications.

Consuming food products containing molecules with antidiabetic effects may significantly impact the consumer's health. Plant-based products, such as tropical fruit byproducts, are considered to have minimal toxicity/side effects as compared to synthetic ones (WHO, 2002). Previous studies using phenolic compounds from papaya seeds and pineapple byproducts revealed α-amylase and α-glucosidase inhibition and antiglycation potential *in vitro* (Riya et al., 2014; Agada et al., 2021). Phenolics from mango peel exerted *in vitro* α-amylase and α-glucosidase inhibition effect. In addition to those effects, byproducts from papaya, pineapple and mango have also shown significant antioxidant activity (Preciado-Saldaña et al., 2022).

Therefore, the aim of this study was to analyze the physico-chemical composition, techno-functional properties and *in vitro* antioxidant and antidiabetic activities of papaya, pineapple and mango peels.

MATERIALS AND METHODS

Vegetable materials

Mango cv. 'Ataulfo', papaya cv. 'Maradol' and pineapple cv. 'Esmeralda' were obtained from a local supermarket in Hermosillo, Mexico. Fruits of commercial maturity and free of apparent damage were selected, washed with tap water, and disinfected with 300 ppm sodium hypochlorite for 3 min. Peels were separated using a sanitized stainless-steel knife and dried at 40 °C for 18 h in an air circulation oven (FD-23, Binder Gmbh, Tuttlingen, Germany). Dry peels were ground to a coarse powder and sieved to obtain flour. Dry peel powders of mango (MAPP), papaya (PAPP) and pineapple (PIPP) were stored in amber bags until analysis.

Proximate and physicochemical analyses

Moisture, ash, lipid, and protein content were determined according to official AOAC methods (Helrich, 1990). Total dietary fiber (TDF), insoluble dietary fiber (IDF), and soluble dietary fiber (SDF) was determined by the method of Asp et al. (1983) and expressed as g/100 g. The pH was determined with a pH meter (Fisher Scientific AB150, Ottawa, Canada), water activity (Aw) was evaluated with theAqualab CX 2T (Decagon devices Inc., Pullman, USA) at 25 °C. The CIE L*, a* and b* color variables were determined utilizing a CR-400HS colorimeter (Konica Minolta Sensing, Inc., Osaka, Japan).

Techno-functional properties

The water holding capacity (WHC) and the oil holding capacity (OHC) were measured according to Wu et al. (2010). The results were expressed as g/g water and g/g oil, respectively. Swelling capacity (SC) was determined by the method of Robertson et al. (2002). The results were expressed as mL/g.

Determination of glucose adsorption capacity (GAC)

GAC was determined according to Ou et al. (2001) and reported as adsorbed glucose per g of powdered peel (mmol/g).

Glycation inhibition

Inhibition of protein glycation was measured as previously described by Nakagawa et al. (2002). Glycation inhibition was reported as percentage. Aminoguanidine was used as a positive control.

Structure analysis

Surface morphology was evaluated with scanning electron microscopy (SEM). The microscope (JEOL JSM-5410LV, Oxford Instruments) was equipped with an INCA system and a dispersive X-ray detector was operated at 20 kV. Scanning images for each sample were taken at 5000 x magnification.

Fourier transform infrared (FT-IR) spectroscopy

FT-IR spectra of sample fragments were recorded using the attenuated total reflectance (ATR) technique in an infrared spectrophotometer with Fourier transform (Nicolet Instrument Corp., Madison, Wisconsin, USA), with a spectral resolution of 4 cm^{-1}.

Extract preparation

The extracts were obtained according to the methodology described by Fontes-Zepeda et al. (2022) and utilized to determine total soluble phenolic compounds, antioxidant activity, α-amylase and α-glucosidase inhibition and antyglication potential.

Total soluble phenolics (TSP), chromatographic identification of phenolic compounds and antioxidant capacity

TSP was determined using the Folin-Ciocalteu method (Singleton et al., 1965). Absorbance was read at 765 nm and results were expressed as mg gallic acid equivalents/g (mg GAE/g).

The extracted phenolic compounds were determined according to Velderrain-Rodríguez et al. (2018) in a diode array detector ultra-resolution liquid chromatography system (UPLC-DAD; ACQUITY, Waters Corp., Milford, MA, USA). Separation was performed on a BEHC 18 column (1.7 µm, 3.0 x 100 mm Milford, MA, USA) at 60 °C. Phenolic compounds were identified by matching their spectral characteristics against standards or derived from published data.

Antioxidant capacity was determined using the 2,2-azinobis-(3-ethylbenzothiazoline-6-sulphonate) (ABTS) according to Re et al. (1999), while the 2,2-diphenyl-1-picril-hydracyl (DPPH) assay as described Brand-Williams et al. (1995). Antioxidant capacity is presented as the result of triplicate measurements and expressed as µmol TE/g. In addition, the inhibitory effect of nitric oxide (NO) formation was evaluated using sodium nitroprusside and the Griess reagent (Giraldo et al., 2003), and the inhibition of superoxide radical formation (O_2^-) was also analyzed (Rojano et al., 2012). Results are expressed as percentage.

α-amylase and α-glucosidase inhibition assays

The α-amylase inhibition assay was performed according to the assay adapted from the Worthington Enzyme Manual (1993). The absorbance was recorded at 540 nm. The α-glucosidase inhibition assay was determined according to Cuevas-Juárez et al. (2014). The absorbance was recorded at 405 nm. Enzymatic inhibitions were measured with a 96-well microplate reader. 1 mM acarbose was used as control.

Statistical analyses

All experiments were performed in triplicate, and results were expressed as mean ± standard deviation (SD). A comparison of means was made using Tukey method with a significance level of $p < 0.05$. Statistical analyses were performed using the NCSS 2012 software (NCSS, LLC, Kaysville, UT, USA).

RESULTS AND DISCUSSION

Chemical and physicochemical properties

Table 1 shows the proximate analysis of the studied fruit peel powders, which had relatively low moisture content (5.98 to 6.20 g/100 g). According to James (2013), moisture of 0-13 g/100 g avoids the action of microorganisms during storage; thus, MAPP, PAPP, and PIPP are in the appropriate range that will inhibit bacterial proliferation. Content of moisture in PIPP (5.69 g/100 g) was lower than the data reported by Sengar et al. (2021) (6.05 g/100 g); PAPP also had a lower value (6.56 g/100 g) than the one reported by Jiang et al. (2021) (17.59 g/100 g), while the value of MAPP (7.42 g/100 g) was within the reported ranges of mango peel (5.39–6.06 g/100 g) (Kaur et al., 2018). MAPP, PAPP, and PIPP had a low lipid content, ranging from 1.27 to 2.27 g/100 g for PAPP. The ash content of MAPP and PIPP for mango peel and papaya byproducts is within the range of 2.43 g/100 g and 2.18 to 5.64 g/100 g reported by Selani et al. (2014) and Lopez-Nunez et al. (2018), respectively. However, in the present study, the value of PAPP is 6.35 g/100 g, lower than that reported in papaya peel (10.15 g/100 g) by Jiang et al. (2021). Although some differences may be attributed to the fruits' ripening stage, cultivar, and postharvest practices, the most important factors affecting this variable are the environmental conditions and agricultural practices (Kim et al., 2019).

Table 1: Proximate analysis of mango (MAPP), papaya (PAPP), and pineapple (PIPP) peel powders

Characterization	MAPP	PAPP	PIPP
Proximate analysis			
Moisture (g/100 g)	6.30 ± 0.04^a	5.98 ± 0.03^c	6.16 ± 0.04^b
Protein (g/100 g)	7.42 ± 0.34^a	6.56 ± 0.23^b	5.69 ± 0.31^c
Lipids (g/100 g)	1.98 ± 0.13^b	2.25 ± 0.10^a	1.27 ± 0.02^c
Ash (g/100 g)	2.53 ± 0.18^c	6.35 ± 0.25^a	3.67 ± 0.17^b
TDF (g/100 g)	54.53 ± 0.05^b	37.77 ± 2.08^C	62.26 ± 0.83^a
IDF (g/100 g)	37.03 ± 0.15^c	30.61 ± 0.10^b	51.45 ± 1.33^a
SDF (g/100 g)	17.50 ± 0.95^a	7.16 ± 0.26^c	10.81 ± 0.62^b

Results are expressed as mean ± standard deviation (n = 3). Means with different letters in rows show statistical differences ($p<0.05$)

Total dietary fiber (TDF), insoluble dietary fiber (IDF), and soluble dietary fiber (SDF) content of the peel powders are shown in Table 1. The studied samples had a TDF ranging from 37.77 to 62.26 g/100 g, where the IDF fraction was higher than the SDF fraction in all samples, indicating that they contain significant amounts of cellulose and hemicellulose (Martínez et al., 2012). PIPP showed the highest IDF and SDF content, followed by MAPP and PAPP. The addition of these fractions to an edible product may have various benefits, including some related to inducing satiety and increasing fecal volume and weight, thereby promoting a normal/healthy digestive system function (Dhingra et al., 2012). IDF could be utilized in the food industry as an ingredient to improve the content of indigestible compounds (Navarro-González et al., 2011). Since fiber has been utilized as an ingredient with particular functions during food production, should be noted that the presence of phenolic compounds together with fiber makes tropical fruit peels a potential functional ingredient.

MAPP had the highest pH of all samples studied (Table 2), which was like values of 4.56–4.83 reported by (Dereje and Abera, 2020) in mango 'Tommy Atkins', PIPP showed a slightly lower pH (4.04) when compared to the data of 4.08 reported for pineapple byproducts (Selani et al., 2016). PAPP had a pH of 3.86, similar to the one reported for papaya byproducts by Silva et al. (2020). All peel powders had low Aw, ranging from 0.21 to 0.24 (Table 2), similar to those previously reported for tropical fruit powders (Prakongpan et al., 2002). The combination of low pH and Aw of the studied peel powders could indicate a low risk of enzymatic or nonenzymatic deterioration and microorganism proliferation (Alp and Bulantekin, 2021). Sample color was dependent on fruit type, variety, and ripeness stage when byproducts were processed into peel powders. Drying had a significant impact, inactivating both enzymatic and nonenzymatic browning reactions (Khiari et al., 2021). Color is one of the most significant quality parameters that influence consumer acceptance of foods; thus, the possible changes exerted by adding byproducts to an edible product should be considered. MAPP showed the highest (L*) value ($p < 0.05$), followed by the PAPP and PIPP samples (Table 2). For the red-green coordinate (a* value), the results were significantly different ($p< 0.05$) between samples. PAPP had the highest a* values, probably due to its high content of red carotenes (carotenoids) which impart it a red color. The highest b* value ($p <0.05$) was measured in MAPP, indicating that this peel has a more pronounced yellowish color, which was expected due to the natural color of the variety of mango for this byproduct. The a* and b* coordinates are also affected by the physical integrity of the fiber, the pigment content, and the disposition of water (López-Vargas et al., 2013).

Techno-functional properties

The techno-functional properties of fruit peel powders are related to factors like fruit source, the chemical structure of their polysaccharides, porosity, preparation conditions (such as temperature and time), and molecular interaction with other compounds (Elleuch et al., 2021). WHC, OHC and SWC of tropical fruit peel powders were evaluated; results are shown in Table 2.

Table 2: physico-chemical and technofunctional properties of mango (MAPP), papaya (PAPP), and pineapple (PIPP) peel powders

Characterization	MAPP	PAPP	PIPP
Physico-chemical properties			
pH	4.53 ± 0.23^{a}	4.03 ± 0.15^{b}	4.04 ± 0.15^{b}
Aw	0.22 ± 0.01^{ab}	0.21 ± 0.01^{b}	0.24 ± 0.01^{a}
L*	68.03 ± 0.30^{a}	63.26 ± 0.05^{c}	60.79 ± 0.11^{b}
a*	0.60 ± 0.01^{b}	0.11 ± 0.02^{c}	6.10 ± 0.15^{a}
b*	33.21 ± 0.08^{a}	26.48 ± 0.05^{b}	22.76 ± 0.11^{c}
Techno-functional properties			
WHC (g water/g powder)	4.36 ± 0.23^{c}	5.26 ± 0.14^{b}	6.39 ± 0.07^{a}
OHC (g oil/g powder)	4.30 ± 0.23^{a}	4.40 ± 0.11^{a}	3.83 ± 0.12b
WSC (mL/g)	7.71 ± 0.41^{c}	8.27 ± 0.23^{b}	18.12 ± 0.98^{a}

Results are expressed as mean ± standard deviation (n = 3). Means with different letters in rows show statistical differences ($p<0.05$)

WHC is the ability of a moist sample to hold water when exposed to compression or centrifugal gravity (Vázquez-Ovando et al., 2013). WHC of PIPP was higher than MAPP and PAPP. In general, the WHC of each peel powder correlates with its IDF content (Table 1). The WHC values obtained were comparable to those reported by Selani et al. (2014) in pineapple byproducts and by Abdul Aziz et al. (2012) for mango peel but lower than those reported in papaya peel and residual pulp (de Moraes Crizel et al., 2016). These differences could be due to various factors, including the edible part used in the different studies.

OHC is the capacity of a sample to retain oil and is one of the most important techno-functional characteristics considered in different food applications to prevent fat losses upon cooking, especially for cooked meat products (Abd El-ghfar et al., 2016). OHC is also a significant nutritional parameter since it can impact a product's ability to absorb or bind cholesterol as well as bile acids and increase their excretion, lowering the concentration of plasma cholesterol as a consequence (Naumann et al. 2019). Peel powders had OHC values that ranged from 3.83 to 4.40 g oil/g, with no statistical differences between samples ($p> 0.05$). These values overlapped with those previously reported in pineapple and mango byproducts (3.45 and 3.81 g/g oil, respectively) (de Moraes Crizel et al., 2016) but were higher than those reported by Nieto-Calvache et al. (2019) in papaya peels (1.54 g/g oil). This difference could be attributed to the intrinsic physical characteristics of the peels, such as porosity, which can be altered due to the different processing conditions, such as drying methods and processing time. Fig. 1 shows the WHC and OHC of mango peel powders. SWC is another important hydration property of a sample directly correlated to its SDF content. It describes to the volume of water occupied by dietary fiber when immersed in excess water. PIPP had the highest SWC (18.2 mL/g), followed by MAPP (8.27 mL/g) and PAPP (7.71 mL/g), and were comparable to the values reported by López-Vargas et al. (2013) in pineapple byproducts and by others in mango peel (García-Magaña et al., 2013). However, the value obtained for PAPP (31.33 mg/mL) was lower than those values reported by Nieto-Calvache et al. (2019).

Effects on glucose adsorption capacity (GAC)

GAC is applied to represent the performance of dietary fiber in adsorbing glucose during gastrointestinal transit *in vivo* (Peerajit et al., 2012). Table 3 shows that all powder

Table 3: The glucose absorption capacity of mango (MAPP), papaya (PAPP), and pineapple (PIPP) peel powders in different concentrations of glucose

Peel powder	Glucose bound (mmol/g)				
	10 mmol	25 mmol	50 mmol	100 mmol	200 mmol
MAPP	1.25 ± 0.06^{a}	2.20 ± 0.02^{b}	4.31 ± 0.06^{b}	8.31 ± 0.11^{b}	18.67 ± 0.13^{b}
PAPP	1.08 ± 0.18^{b}	2.02 ± 0.06^{c}	4.03 ± 0.07^{c}	7.22 ± 0.09^{c}	16.65 ± 0.11^{c}
PIPP	1.41 ± 0.05^{a}	2.43 ± 0.10^{a}	4.65 ± 0.11^{a}	9.26 ± 0.07^{a}	22.45 ± 0.47^{a}

Values are presented as mean ± standard deviation (n = 3). Means with different letters in rows show statistical differences ($p<0.05$)

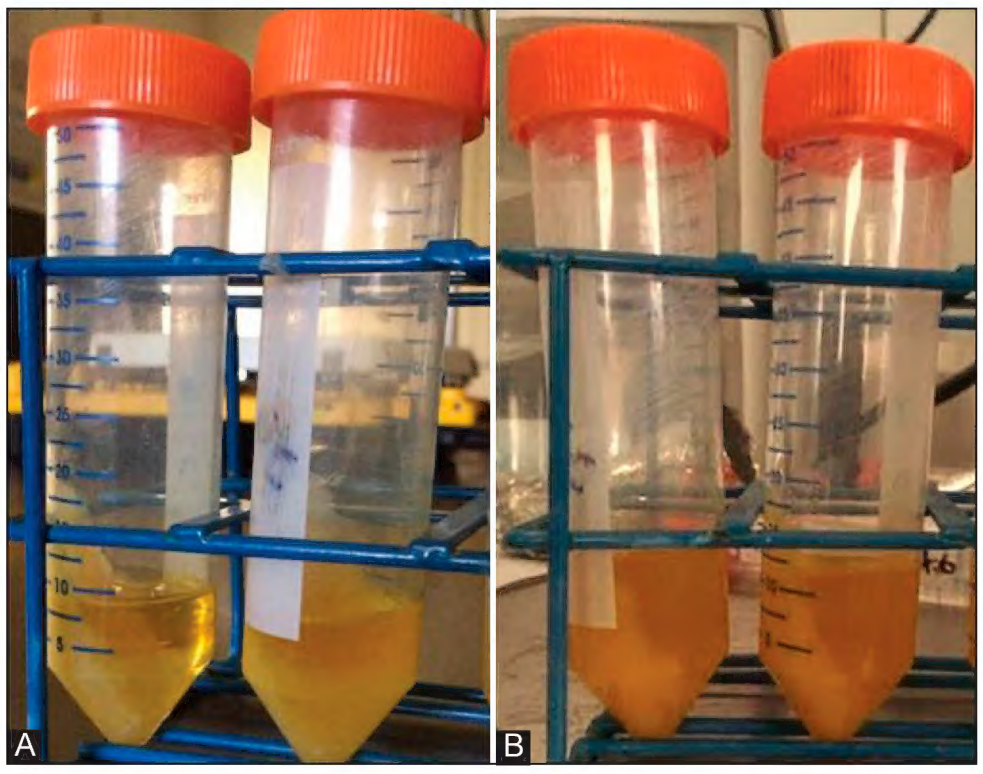

Fig 1. (A and B) The water holding capacity (WHC) and the oil holding capacity (OHC) of mango peel powders.

peel samples were able to bind glucose in a concentration-dependent manner. It was also noted that GAC of PIPP was significantly higher ($p < 0.05$) than MAPP and PAPP. The GAC of the samples may be attributed in part to the presence of dietary fiber, which promotes the entrapment of glucose molecules (Table 1). It has been reported that fruit byproducts adsorb glucose in different concentrations and that the amount of adsorbed glucose increases in parallel with the concentration of glucose in the solution (de Souza et al., 2018). It was also observed that GAC of PIPP was all greater than that of MAPP and PAPP at different concentrations, which could be attributed to its larger particle size and lower moisture contents, contributing to its ability to absorb glucose molecules (Zheng et al., 2019). It is also remarkable that the samples were effective in adsorbing glucose even at low concentrations. The studied fruit peel powders could absorb glucose in the small intestine even at low concentrations, reducing the bioaccessibility of glucose in the gut and reducing its absorption and impact on postprandial glycemia (Papoutsis et al., 2021).

Scanning electron microscopy

Fig. 2a (MAPP), 2b (PAPP), and 2c (PIPP) show the surface of the studied peel powders. In general, the granules had mostly irregular amorphous shapes, were of different sizes and had solid structures. The amorphous structures of irregular appearance, rough and slightly fibrous surface may be due to microstructural damage to the cell walls due to the water losses and segregation of components during drying (Sengar et al., 2021). Drying processes tend to produce changes at the microstructural level in peels, causing rigidity and damage to the cellular tissue (Lewicki and Pawlak, 2003). The fibrous characteristic that distinguishes them is related to their chemical composition, possessing a higher fiber content of more than 36% (w/w).

Fourier transform infrared spectroscopy

FTIR spectroscopy was performed to identify the major functional groups present in fruit peel powders, as shown in Fig. 2E (MAPP), 2F (PAPP), and 2G (PIPP). In general, peaks in the 3600–3000 cm^{-1} correspond to OH stretching, which could be attributed to H-bonded OH groups or phenolic compounds. The 2900–2700 cm^{-1} peaks show aliphatic C-H stretching from carbonyl-containing (aldehydes) aromatic compounds (Henning et al., 2019). The bands in the 1760-1650 cm^{-1} region are characteristic of non-esterified and esterified carboxyl groups in pectin, characteristic of all samples analyzed. The weak peak around 1730-1735 cm^{-1} is related to the carbonyl C=O stretching vibration of groups such as carboxylic acids, aldehydes, acetyl, and ketones (Horikawa et al., 2019). The CH_2 asymmetrical and symmetrical stretching of alkane groups were associated with the medium peak near 2921 cm^{-1}, and the weak signal at 2850 cm^{-1}, respectively (Kumar et al., 2019). The strongest sharp signal located around 1028 cm^{-1} was designated to C_6–O_6H, C–O, C=O and C–C–O stretching, denoting phenols, alcohols, and esters, while the narrow peak at 820 cm^{-1} presented C–H out plane bending (Szymanska-Chargot and Zdunek, 2013). The 776 cm^{-1} peak could be assigned to C–H deformation in aromatic carbohydrates and lignin; several peaks near 1372 cm^{-1} can be attributed to cellulose and hemicellulose (Zhao et al., 2016). The occurrence of three bands confirmed the presence of phenolic compounds: 3600-3200 cm^{-1} (O–H stretching), 1410-1320 cm^{-1}, and 1260-1180 cm^{-1}, which result from the interaction of angular deformation of O–H and C–O stretching (de Almeida et al., 2007).

Total soluble phenolics and antioxidant activity

TSP found present in MAPP, PAPP, and PIPP were 18.67, 10.78 and 16.99 mg GAE/g, respectively (Table 4). These values were lower than those reported by Vithana et al.

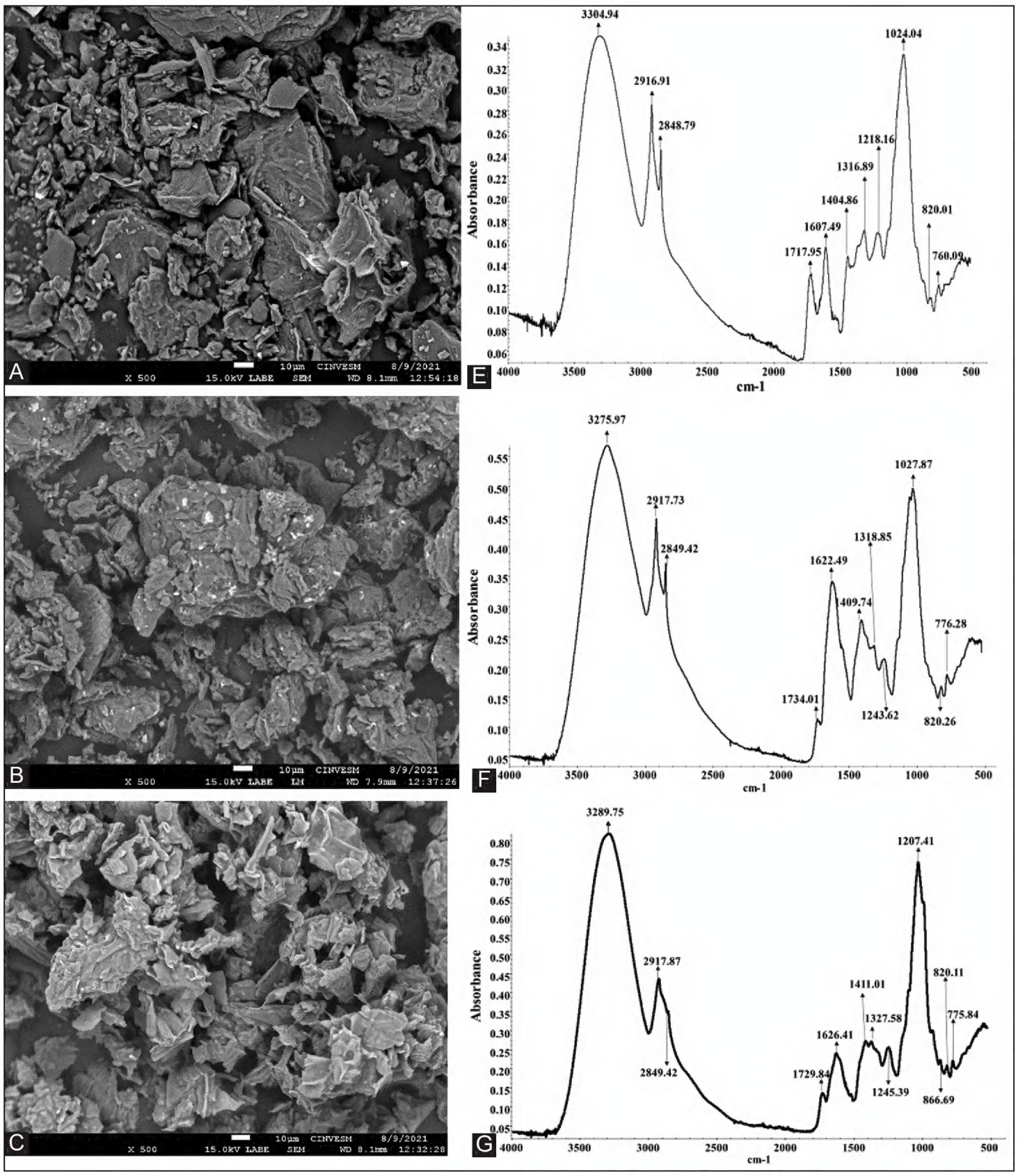

Fig 2. SEM and FTIR of mango (MAPP 2A, 2E), papaya (PAPP 2B,2F), and pineapple (PIPP 2C, 2G) peel powders.

Table 4: Total soluble phenolics (TSP) and phenolic compounds of mango (MAPP), papaya (PAPP), and pineapple (PIPP) peel powders

Content	MAPP	PAPP	PIPP
TPS (mg GAE/100 g)	180.67 ± 2.01^{a}	107.88 ± 4.19^{c}	169.22 ± 3.92^{b}
Gallic acid (µg/g)	106.27 ± 4.87^{b}	317.22 ± 14.65^{a}	9.37 ± 0.06^{c}
Ferulic acid (µg/g)	18.6 ± 1.11^{c}	195.03 ± 7.20^{a}	72.42 ± 0.03^{b}
p-coumaric acid (µg/g)	1.13 ± 0.06^{c}	533.98 ± 20.61^{a}	7.47 ± 0.04^{b}
Catechin (µg/g)	98.65 ± 7.59^{c}	585.16 ± 31.24^{a}	ND
Mangiferin (µg/g)	355.39 ± 10.42	ND	ND
Quercetin-3-β-d- glucoside (µg/g)	22.76 ± 1.83	ND	ND

Results are expressed as mean ± standard deviation (n = 3). Means with different letters in rows show statistical differences ($p<0.05$)
ND: Not detected.

(2018) in mango peel (96.2 mg GAE/g) and in papaya and pineapple byproducts (15.35 and 12.28 mg GAE/g) (Abd El-ghfar et al., 2016; de Moraes Crizel et al., 2016), but higher than those reported in other mango peel cultivars (3.70 mg GAE/g) (García-Magaña et al., 2013), papaya peels (9.6 mg/mg GAE/g) and pineapple peels (3.79 mg GAE/g) (Selani et al., 2016). These differences may be due to the variety of the fruit used, ripening, the drying processes used, and specific conditions during extract production.

The determination of phenolic compounds (Table 4) revealed the presence of seven individual molecules, namely,

ferulic acid, gallic acid, *p*-coumaric acid, quercetin, catechin reported papaya, and pineapple peels (Li et al., 2014; Fontes-Zepeda et al., 2022); quercetin-3-β-d-glucoside and mangiferin. Mangiferin is the main component in mango peel, and its identification agrees with the identifications reported in mango peels (Fontes-Zepeda et al., 2022; Preciado-Saldaña et al., 2022).

The mechanism of action of the antioxidant activity methods differs; for example, some have different responses to soluble or hydrophobic compounds. Thus, differences in the antioxidant activity of a sample will depend on its bioactive composition, radical used, and reaction endpoint, among other variables. This suggests the need to evaluate more than one type of measurement of antioxidant activity and the limitations of each methodology (Shahidi and Ambigaipalan, 2015). Therefore, among the different methods commonly used to measure the antioxidant capacity, we selected the inhibition of ABTS and DPPH radicals and the ability to scavenge NO• and O_2^- of extracts.

Table 5 shows the antioxidant capacity of peel powders, as determined by the methods mentioned above. Antioxidant activity ranged from 5.81 to 29.2 μM TE/g and 3.36 to 35.3 μM TE/g for DPPH and ABTS, respectively. Other authors have reported the antioxidant capacity of fruit feel powder, resulting in different values. For example, Fu et al. (2011) reported values of 1.83 and 2.64 μM TE/g for papaya and mango peel, respectively, and Selani et al. (2016) reported values of 5.76 μM TE/g for pineapple byproducts. On the other hand, Parniakov et al. (2014) described values of antioxidant activity of 16.70 and 13.4 μMTE/g for papaya and pineapple peel, respectively, while Vithana et al. (2018) obtained values of 52 μM TE/g for mango peel, as determined by the ABTS method.

The samples' NO· inhibition ranged from 60.67 to 86.35 % (Table 5); in contrast, the NO· scavenging activity of ferulic acid (reference compound) was reported in 93.61%. According to López-00Martínez et al. (2012), the scavenging activities of the extract against NO· are apparently due to phenolic compounds, which are well established as effective free radical scavengers against NO· and peroxynitrite (ONOO). The O_2^- shows an important function in the formation of different reactive oxygen species, including singlet oxygen and hydroxyl radical causing oxidative damage to proteins, lipids, and DNA (Pietta, 2000). O_2^- radical scavenging capacity of extracts from peel powders ranged from 17.56 to 50.64 %, in the following order PAPP<PIPP<MAPP (Table 5). This suggests that mango peel was the best radical scavenger, which might be attributed to its specific phenolic content (Table 4), allowing them to act as free radical scavengers, hydrogen donors, and reducing agents (Rice-Evans et al. 1995). Differences in scavenging capacities are associated with the concentration and specific composition of phenolic compounds. Previous researchers have reported that hydrophilic compounds, such as phenolic compounds, were the main contributors to the antioxidant activity of different tropical fruits (López-Martínez et al., 2012; Velderrain et al., 2018).

Table 5: Antioxidant activities of mango (MAPP), papaya (PAPP), and pineapple (PIPP) peel powders

	DPPH (μM TE/g)	ABTS (μM TE/g)	NO· (%)	O_2^- (%)
MAPP	35.3 ± 1.19^a	29.8 ± 1.55^a	71.89 ± 3.14^b	20.3 ± 1.63^b
PAPP	8.32 ± 0.97^b	5.11 ± 0.61^b	60.67 ± 4.78^c	17.56 ± 0.61^c
PIPP	5.76 ± 0.43^c	3.63 ± 0.19^c	86.35 ± 3.42^a	50.64 ± 5.09^a

Values are presented as mean ± standard deviation (n = 3). Means with different letters in rows show statistical differences ($p<0.05$)

α-amylase and α-glucosidase inhibition by peel powders

The inhibition of α-amylase increased dose-dependently with the concentration of peel extract (Fig. 3a), similar to the inhibition of α-glucosidase (Fig. 3b), although the inhibitory potential against α-amylase was lower than against α-glucosidase. MAPP had the strongest α-amylase and α-glucosidase inhibition effects (51.40 and 70.32%, respectively). The presence of phenolic compounds in peel powders, well-known α-amylase, and α-glucosidase inhibitors, may be a significant factor that determines the samples' inhibitory potential. Suleria et al. (2020) indicate that phenolic acids such as ferulic and gallic acid, detected in byproducts of tropical fruits, are capable of inhibiting α-amylase and α-glucosidase, these phenolic acids were identified in MAPP, PIPP and PAPP (Table 4), IC_{50} values against α-amylase were 0.87, 1.03, and 1.4 mg/mL for MAPP, PIPP, and PAPP, respectively. These values were higher than those described by Pavithra et al. (2017) for papaya peels (29.97 mg/mL) and pineapple subproducts (>200 mg/mL), as reported Podsedek et al. (2014) but lower than values depicted by Preciado-Saldaña et al. (2022) in mango peel (0.089 mg/mL). On the other hand, IC_{50} values against α-glucosidase were 0.57, 0.67, and 0.84 mg/mL for MAPP, PIPP, and PAPP, respectively, which were higher than those reported by Islam et al. (2021), for mango, pineapple and papaya peels (0.25, 0.16, and 0.25 mg/mL, respectively).

The higher inhibition values for MAPP extract (Fig. 3A, B) may be due to the presence of mangiferin and its derivatives, which have demonstrated different beneficial biological activities, such as decreased dialyzed glucose and an antidiabetic effect in rats (Sekar et al., 2019). Although the inhibitor effects were lower than acarbose (78.6%), the results indicated that the powder peels could be good

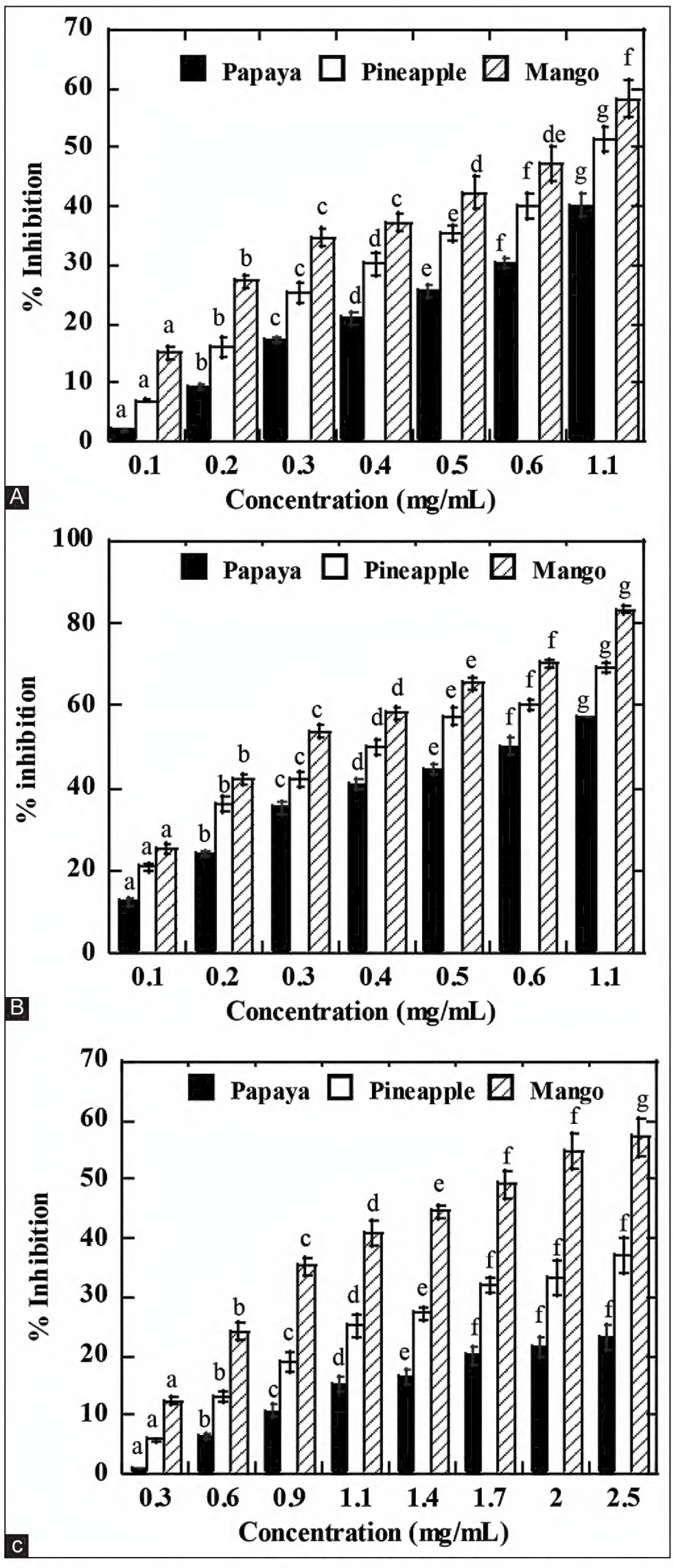

Fig 3. α-amylase A) α- glucosidase B) and antiglycation C) activity of mango (MAPP), papaya (PAPP), and pineapple (PIPP) peel powders. Values are presented as mean ± standard deviation (n = 3). Different literals indicate significant differences ($p<0.05$).

inhibitors of α-amylase and α-glucosidase activities. In fact, it has been found that different peel fruits can inhibit these enzymes with minimum side effects (Azizan et al., 2020). Differences in enzymatic activity among samples may be due to their specific phenolic content, the variety of fruits used, and the origin of the enzymes used.

AGE inhibition

Advanced glycated end products (AGEs) in diabetic patients occur due to poor glycemic control; AGEs are a major contributing factor to the development of diabetic complications, according to their potential to increase oxidative stress that damages tissues and organs (Rhee et al., 2018). The analyzed peels showed a moderate dose-dependent antiglycation activity, according to an IC_{50}= 1.27 mg/mL for MAPP, 2.43 mg/mL for PIPP and non-detected values for PAPP. In addition, an inhibition potential of AGE formation of 23.23, 37.16 and 57.15% at the maximum concentration tested (2.5 mg/mL) for PAPP, PIPP and MAPP, respectively (Fig. 3C). Ferulic acid and gallic acid (both identified in MAPP, PIPP and PAPP) (Table 4) have been reported capable of inhibiting the advanced phase of glycation and decreasing protein carbonyls and AGE formation (Spagnuolo et al., 2021).

Aminoguanidine is a synthetic glycation inhibitor, whose value of antiglycation showed in this study IC_{50} = 0.66 mg/mL and inhibition potential of AGEs formation of 66.6% at 2.5 mg/mL, which is more effective than MAPP, PIPP and PAPP to inhibit the formation of AGEs. Thus, the development of new inhibitors based on natural products could provide a promising therapeutic approach to preventing diabetic complications. According to the literature, studies on the antiglycation activity of tropical fruit peels are scarce, making it necessary to make greater efforts to find sources of natural origin to inhibit the formation of AGEs, such as tropical fruit peels. The results reported here suggest that tropical fruit peels contain bioactive compounds that may be beneficial in controlling or preventing AGEs generation, although their efficacy *in vivo* must still be thoroughly studied.

CONCLUSIONS

The present study suggests that the three fruit peel powders studied can be used as functional ingredients, providing dietary fiber with important physico-chemical composition, techno-functional properties, and antioxidant and bioactive compounds. Mango peel powder showed the highest WHC, OHC, and SWC, which can be a possible candidate to improve texture and reduce a product's caloric density. All peel powders exhibited high TPC content and good scavenging capabilities against the DPPH and ABTS radicals, with pineapple peel powder being the most potent inhibitor of NO· and O_2^- formation. In general, all peel powders possess medium α-amylase and antiglycation

potential, but a stronger α-glucosidase inhibitory activity. Oxidative stress is crucial in the progression and complication of diabetes; thus, the antioxidant and antidiabetic potentials of tropical fruit peel powders suggest that they may be relevant for glycemic control by suppressing carbohydrate digestion and suppressing glycation. Further *in vivo* investigations on the antioxidant and hypoglycemic activities of tropical fruit peel powders, as well as their possible mechanism of action, require further investigation.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest.

Author's contributions

Ofelia Marquez-Molina participated in the development of the experiment. Abraham Jesús Domínguez Ávila, Gustavo Adolfo González Aguilar, and Sunil Pareekverified the analytical methods, discussed the results and wrote the original draft. Tomas Jesús Madera Santana participated in the development of the experiment, and Leticia X. López-Martínez participated in the development of the experiment, discussed the results, and wrote the original draft and supervising the findings of this study.

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